# Missing Growth, Imputation of Price Statistics and Channels of Creative Destruction

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Tiivistelmä – Referat – Abstract

Prices of different products are followed by statistical offices in order to produce price indices. The quality of products is constantly changing due to creative destruction. When a product leaves market, its price is computed with a method called imputation. Recent studies in United States and France have found that use of imputation may lead to upward bias in inflation. Since price indices are used as deflators when calculating economic growth, such a bias would mean that some of the growth is missed. The aim of this thesis is to study whether such a bias exists in Finland and how large it is. In addition, the channels of innovation induced growth are studied in order to determine from where the potentially missed growth originates.

Creative destruction has been incorporated into economic growth models in the early 1990s. In its centre, are firms at the microlevel that innovate and create new products and improve existing ones. It has been shown that it is a key element when economic growth is concerned. New products and improving quality of old varieties is, however, widely recognised problem for price indices. Sources of bias for price statistics has been studied a lot and the changing quality of products is one of the greatest of them. This thesis contributes to this field by recognising a new possible source of bias and its magnitude in Finnish economy.

The model used in this thesis is from 2017 paper by Aghion, Bergeaud, Boppart, Klenow and Li. The model is a new keynesian DSGE model with exogenous innovation and it provides an accounting framework which enables the quantification of missing growth. The missing growth is estimated using a so-called market share approach, where market shares of incumbent and entrant producers are exploited to quantify the share of growth that is missed yearly. Another method, namely indirect inference, relies on simulation of the economic growth model. It infers the arrival rates and step sizes of different types of innovations: incumbent of innovation, creative destruction and new product varieties. The simulation also enables for finding the contributions of those innovation types for the economic growth. The contributions provide information on from which type of innovation the majority of growth comes.

Both methods use data provided by Statistics Finland. They use micro level data on private enterprises in Finland during the years 1989 – 2016. The market share approach requires establishment level data and information on the revenue and employment. The indirect inference method uses the same data aggregated on firm level for the years 1993 – 2013. In addition, the simulation requires total factor productivity growth rate for the given years.

The results suggest that 0.489 percentage points of growth has been missed yearly in Finland during the years 1989 – 2016 when calculated with revenue data. The missed growth was estimated to be 0.532 percentage points per year with employment data. The results are comparable in magnitude with the results from the United States and France. The magnitude has remained stable over the years. The indirect inference method suggests that most of the growth comes from incumbent own innovation: 59.3% in 1993 – 2003 and 57.8% in 2003 – 2013. The rest is due to creative destruction and new product varieties either by incumbents or entrants.

If 0.5 percentage points of growth is missed every year, it would have had significant effects on the economy. For example, many social benefits are tied to price indices and over estimation of them would mean that the benefits have not risen as much as they should have. Given the systematic nature of the bias, the central bank should consider increasing its inflation target. The statistical offices that produce the price statistics may be able to lower the bias if they manage to keep up to date with incumbent own innovations, since the majority of growth is originating from it. Also chain linked index helps lowering the bias by updating the sample and weights on a yearly basis. Additional research is needed in order to find solutions to overcome the bias caused by creative destruction and imputation of missing prices.



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Creative destruction, innovation, economic growth, productivity, price index

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Tiivistelmä – Referat – Abstract

Tilastovirastot seuraavat erilaisten tuotteiden hintoja tuottaessaan hintaindeksejä. Luovan tuhon vuoksi tuotteiden laatu ja ominaisuudet muuttuvat jatkuvasti. Kun tuote poistuu markkinoilta, sen hinta arvioidaan laskennallisesti imputointi-nimisellä menetelmällä. Yhdysvalloissa ja Ranskassa tehdyissä tutkimuksissa imputoinnin on havaittu johtavan inflaation yliarvioimiseen. Tällainen harha tarkoittaa, että osa talouskasvusta menetetään, koska hintaindeksejä käytetään deflaattoreina. Tämän työn tarkoituksena on selvittää, onko vastaava harha havaittavissa Suomessa ja kuinka suuri se on. Lisäksi tutkitaan innovaatioiden aikaansaaman kasvun kanavia, jotta potentiaalisen menetetyn kasvun lähde saataisiin selville.

Luova tuho sisällytettiin kasvumalleihin 1990-luvun alkupuolella. Sen keskiössä ovat mikrotasolla operoivat yritykset, jotka innovoivat ja luovat uusia tuotteita sekä parantavat olemassa olevien ominaisuuksia. Luovan tuhon on osoitettu olevan merkittävä tekijä talouskasvulle. Uudet tuotteet ja vanhojen paranevat ominaisuudet ovat kuitenkin laajasti tunnistettu ongelma hintatilastoinnille. Hintatilastojen harhojen lähteitä on tutkittu paljon, ja laadun muutokset tuotteissa ovat niistä merkittävimpiä. Tämä työ tukee sen alan tutkimusta havaitsemalla mahdollisen uuden harhan lähteen ja sen suuruuden Suomen taloudessa.

Tässä työssä käytettävän mallin esittelivät Aghion, Bergeaud, Boppart, Klenow ja Li vuoden 2017 tutkimuksessaan. Käytettävä malli on uuskeynesiläinen DSGE-malli eksogeenisillä innovaatioilla, joka mahdollistaa menetetyn kasvun kvantifioinnin. Menetettyä kasvua arvioidaan niin sanotun markkinaosuusmenetelmän avulla, jossa vanhojen ja uusien tuottajien markkinaosuuksia hyödynnetään vuosittain menetetyn kasvun määrittämiseksi. Toinen menetelmä, epäsuora johtaminen, nojaa kasvumallin simulointiin. Se johtaa saapumisvauhdit ja laadunparanemiskertoimet eri innovaatio tyypeille, joita ovat vanhojen tuottajien oma innovointi, luova tuho ja uudet tuotevariaatiot. Simuloinnin avulla voidaan lisäksi määrittää, mikä innovaatiotyyppi on vaikuttanut kasvuun eniten.

Molemmissa menetelmissä käytetään Tilastokeskuksen tarjoamaa aineistoa. Käytettävissä on suomalaisia yrityksiä kuvaava mikroaineisto. Markkinaosuusmenetelmä hyödyntää toimipaikkatason tietoja toimipaikkojen liikevaihdosta ja henkilöstömääristä vuosilta 1989–2016. Simulointimenetelmässä hyödynnetään samaa aineistoa, mutta aggregoituna yritystasolle vuosilta 1993–2013. Lisäksi simuloinnissa tarvitaan kokonaistuottavuuden kasvuvauhti kyseisiltä vuosilta.

Liikevaihtotiedoilla laskettuna Suomessa on menetetty keskimäärin 0,489 prosenttiyksikköä kasvusta vuosittain vuosien 1989–2016 välisenä aikana. Vastaava luku henkilöstömäärillä laskettuna oli 0,532 prosenttiyksikköä. Menetetty kasvu on pysynyt vakaana vuodesta toiseen ja on suuruudeltaan vastaavaa luokkaa Yhdysvalloista ja Ranskasta saatujen tulosten kanssa. Simulointimallin mukaan suurin osa kasvusta johtui vanhojen tuottajien omista innovaatioista: 59,3% vuosina 1993–2003 ja 57,8% vuosina 2003–2013. Loput kasvusta johtui luovasta tuhosta ja uusista tuotevariaatioista.

Mikäli kasvuvauhti on todellisuudessa ollut 0,5 prosenttiyksikköä suurempaa kuin on mitattu, on sillä merkittäviä vaikutuksia Suomen taloudelle. Esimerkiksi monet sosiaalietuudet on sidottu hintaindekseihin, ja niiden yliarvioinnin seurauksena etuudet ovat todennäköisesti nousseet liian vähän. Myös keskuspankkien tulisi harkita inflaatiotavoitteidensa uudelleen arviointia, sillä harha on pysynyt vakaana vuodesta toiseen. Koska suurin osa kasvusta johtuu vanhojen tuottajien innovoinnista, on tilastoviranomaisilla mahdollisuuksia pienentää harhaa seuraamalla otoksessa mukana olevien tuottajien innovointia. Myös ketjuindeksiin siirtymällä harhaa voidaan pienentää, sillä silloin otosta ja painoja voidaan päivittää vuosittain. Lisää tutkimusta tarvitaan, jotta löydetään keinoja imputoinnin ja luovan tuhon aiheuttaman harhan kitkemiseksi.



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Luova tuho, innovaatio, talouskasvu, tuottavuus, hintaindeksi

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# 1 Introduction

Statistical offices follow the price development of significant number of products in order to produce different price indices. Sometimes products disappear from the markets simply because they become obsolete and are replaced by new and better products or varieties. New higher quality versions of existing products is a known difficulty for the price indices since the price change driven by the quality improvement does not necessarily reflect the actual price development of the product. This quality growth will probably lead to a bias in the price indices (Bils, 2009; Moulton, Moses, Gordon and Bosworth, 1997). In the case where the product is replaced by a brand new one, statistical offices continue to estimate the price development of disappearing products using a method called imputation. This means that the missing price is estimated by using the average price development of the other products within the same product class until the price of the new product is obtained (Statistics Finland, 2013).

The phenomenon where old obsolete products are being replaced by new and better ones is called creative destruction. It has become widely recognized source of economic growth (Aghion and Howitt, 1992) and it has also been showed how growth has historically stopped in countries where creative destruction has been opposed (Robinson and Acemoglu, 2012). In a study published in 2017 (Aghion, Bergeaud, Boppart, Klenow and Li, 2017), it is argued that creative destruction may lead to a substantial bias in price indices if statistical offices use imputation. Inflation is probably below-average for products subject to creative destruction (Aghion et al., 2017) and hence the use of imputation may lead to over-estimation of inflation. Upward bias in the inflation rate would in turn mean a downward bias in the real economic growth rate. Given that such a bias exists, it would mean that part of the growth is 'missed' every year due to imputation.

The purpose of this study is to conduct a similar research in Finland, using Finnish data. Using establishment level micro data on private enterprises, this paper tries to find out whether imputation of missing prices lead to bias in the inflation in Finland. In addition, the channels of growth through creative destruction will be examined, following the methodology of Garcia-Macia, Hsieh and Klenow, 2016. Results from this research may, in addition, explain partly the recent phenomenon where the growth of productivity has slowed down during the 2000s, especially after 2008 in Finland. If the missing growth has increased over these years, it could explain the slowing growth rate of productivity.

The research done in the United States suggested that the missing growth from the use of imputation is approximately 0.6 percentage points per year and that most of it is due to creative destruction (Aghion et al., 2017). As same imputation methods are used in Finland, the expected results of this paper are similar. However, the magnitude is expected to be smaller due to the differences in the structure and size of the economies of Finland and the United States.

This study is organized as follows. In the next section the background of the research topic is described more thoroughly with an extensive literature review on the previous studies on the subject. Attention is focused for the creative destruction and its working mechanics together with description of sources of bias in price indices and imputation methods used by statistical offices. In the third section the model by Aghion, Bergeaud, Boppart, Klenow and Li is examined. Data and methods used for the empirical part of this study are introduced in the section four. Section five presents the results and section six concludes.

# 2 Related literature and previous studies

The connection of bias in the inflation caused by imputation and the creative destruction has not been studied a lot previously. The study made in the United States (Aghion et al., 2017) is probably the only one tackling this exact issue. That study is therefore examined more in detail in the next section. However, in order to provide the reasoning for the topic, it is essential to discuss the effect that the creative destruction has on the economic growth and productivity. In addition, the method of imputation and other difficulties and possible sources of bias in price indices should be given attention to.

## 2.1 Creative destruction

The term *creative destruction* can be seen as a concept that illustrates the micro-level dynamics of economic growth (Maliranta, Rouvinen and Ylä-Anttila, 2010). The term itself is not a new one. It was popularized by Joseph Schumpeter in 1942 in his book 'Capitalism, Socialism and Democracy' (Schumpeter, 1942) where he stated this widely quoted expression:

> "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates."

Schumpeter understood the importance of innovations and the impact they may have on the economic growth. In fact, he claimed that in a capitalist system the economy never is and never can be stationary. Instead, it is subject to continuous evolutionary development driven by new innovations and ways of producing – creative destruction (Schumpeter, 1942).

However, the literature and research on creative destruction has developed a lot from the days of Schumpeter. Since then the creative destruction has become an important piece of many growth theories (Garcia-Macia et al., 2016). However, these growth models with creative destruction started properly see the day light only after the emergence of endogenous growth theories.

### 2.1.1 Growth theories

Endogenous growth theories emerged mainly in the 1980s and they were build on the significant contributions made earlier, for instance the work by Kenneth Arrow (Arrow, 1962). Paul Romer's theory (Romer, 1990) can be seen as the work that set the endogenous growth theories properly in motion. After that, the theory has been improved and modified by adding for example research and development into the model.

Endogenous growth literature emphasize the significance of knowledge, innovations and human capital. Accumulation of knowledge may be caused by various things: education, training and scientific research to mention a few. However, this paper focuses on the innovations that generate new better products and make previous ones obsolete. One version of a model of growth that takes this creative destruction into account was published by Aghion and Howitt in 1992. (Aghion and Howitt, 1992.)

In their model, Aghion and Howitt assume that research produces innovations with Poisson arrival rate. Research requires skilled labor and therefore the economy will not grow if resources are not allocated to research (via skilled labor). Innovations will in turn improve the production technology and hence the productivity. Another incentive to innovate new products is the possibility to obtain monopoly rents in the next period due to patenting the innovation. In their model, growth is the result of technological progress and this progress emerges from the competition between research companies that create and develop new innovations. (Aghion and Howitt, 1992.) The presumption that creative destruction originates from the competition where firms try to innovate new products with better quality-price ratio than their competitors is typical for so-called Schumpeterian growth models (Maliranta, 2014b).

A more recent example of economic model with innovation in its center is by Klette and Kortum, 2004. They formulated a model of innovating firms that grow through innovations in products new to them. The increase in quality of certain set of products due to innovation will lead to economic growth. Innovation rate of a firm depends on its investments in R&D and its knowledge capital. Another interesting aspect of their theory is that firms' success always comes at the expense of competitors and that eventually firms will have to exit the markets after receiving series of 'destructive shocks' (Klette and Kortum, 2004).

### 2.1.2 Productivity

As it was already stated, creative destruction may have a substantial impact on the productivity within an economy. New innovations that create new ways of producing other goods and services, or improve the old ways of producing are essential for the productivity growth. It is widely believed that productivity growth is the key factor of welfare and competitiveness of an economy (Maliranta, 2014a). As it is suggested in Aghion and Howitt, 1992, creative destruction and technological progress that drives productivity and economic growth is tightly related to research and development. Therefore, it is not surprising that Maliranta finds that the creative destruction has the greatest impact on the productivity growth in industries where R&D is common in Finland (Maliranta, 2014a). Technology industry is an example of that kind of innovative industry.

The connection between Finland's relatively rapid productivity growth starting from mid-1980s and creative destruction has been studied by Maliranta, Rouvinen and Ylä-Anttila (2010). They argue that creative destruction played crucial role in the 'Finland's path to the global productivity frontier'. Indeed, the productivity growth has been significant: labor productivity grew 4-fold during the years 1970-2007. Contribution of telecommunications equipment following the success of Nokia in the late 1990s has been emphasized in Finland. However, Maliranta et al. point out that creative destruction had significant effect on the labor productivity growth long before that. (Maliranta et al., 2010.)

Another characterizing property of Finnish economy is its regional dispersion as far as productivity growth is concerned. According to Böckerman and Maliranta (2007), southern, more urbanized part of Finland experienced 0.9 percentage points higher labor productivity growth rate than more rural eastern Finland in 1975-1999. What makes it interesting is that they found no regional disparities between the two in the average rate of productivity growth for incumbent plants. Instead, the differences originate from creative destruction: firm entry, exit and reallocation of resources within industries which has been significantly stronger in Southern Finland. (Böckerman and Maliranta, 2007.)

Productivity growth in the United States but also in other developed economies has slowed down during 2000s and 2010s. Reason to this slowdown is not known but many explanations have been offered. Mismeasurement of gains from innovations in information technology sector is one suggested reason. Intuition behind this explanation is the "nonmarket" nature of modern IT services such as Google search and Facebook. Use of these nonmarket services may nevertheless have an impact on productivity of labour and consumers and welfare within the economy. However, there is little evidence supporting that claim (Byrne, Fernald and Reinsdorf, 2016). In the paper by Byrne, Fernald and Reinsdorf, it is stated that the effect of nonmarket services mentioned earlier is still not significant enough to explain the magnitude of the slowdown (Byrne et al., 2016). The purpose of this thesis is not to try to find the reason for this productivity growth slowdown. However, if the missing growth due to creative destruction and imputation has increased over the years when productivity growth has slowed down, it could be one factor affecting it.

Another mechanism that affects the productivity growth with the help of creative destruction is firm dynamics. Small and young firms such as start-ups are often bringing new innovations to markets. The innovative nature of young businesses may also have a significant impact on the productivity of larger and older incumbent firms. The threat of a new firm to enter markets may increase the willingness of incumbents to innovate. Small businesses with interesting new innovations and ideas are also often bought by larger companies, who in turn will improve their productivity by doing so. (Haltiwanger, 2015.) Firm dynamics and its connections with creative destruction and growth are discussed more in detail in the following section.

### 2.1.3 Firm Dynamics

The role of entrepreneurship and firm dynamics and their impact on productivity and economic growth has been studied quite a lot. Creative destruction has a key role in the way entering and exiting firms affect the productivity development within the markets. New entrepreneurs usually have a new innovative idea or a better way to produce existing products as they start a new firm and try to enter the markets. Innovative entrants force incumbent firms to stay alert and invest in innovative actions and try to improve their efficiency (Bosma, Stam and Schutjens, 2011). As innovative entrants that are more productive than average incumbents enter the market, the less productive incumbents may be forced to exit. Firm exit allows its employees and other possible resources to be allocated to the more productive firms and therefore creative destruction may not always have positive impact on employment (Bosma et al., 2011).

As entering and exiting firms are studied in the empirical part of this study, an important phenomenon called *a revolving door regime* is good to keep in mind. The revolving door regime refers to a situation where entry rate is high but a great number of these entrants will be exiting soon after the entry. The new firms may not have brought sufficient improvements in the production methods or newly innovated products may not be profitable or useful. New entrepreneurs may also lack sufficient skills to run a business. It is also possible that as the entrants do not have technological advantage, they offer the same products as their competing incumbents and therefore, some firms will be crowded out (Audretsch and Fritsch, 2002; Bosma et al., 2011). *The revolving door* mechanism has been observed to be present also in Finland and it is found to be time consuming process. Entry's contribution to exits is declining steadily over a period of first 10-15 years of the life cycle (Maliranta et al., 2010). This is one reason why an entrant will be defined to be a firm that has already been in the market for a few years in the empirical part of this study.

Bosma, Stam and Schutjens (2011) have studied the effect of firm entry and exit on the productivity growth in regional level. They find that entry and exit are improving the competitiveness and productivity in service sector but not in manufacturing. Reasons for this are not known for sure but the authors suggested that the minimum efficiency scale in service activities may be one reason. Small entrants in the service sector can therefore have bigger impact on the productivity in service sector than in manufacturing sector that is (in Netherlands but also in Finland) dominated by large companies. Knowledge spillovers may also take place faster in service sector whereas in manufacturing, new innovations are usually protected with patents (Bosma et al., 2011). A study made in Finland differs drastically from the results in Netherlands. Maliranta et al. (2010) found that entry, exit and resource reallocation has contributed significantly to Finnish productivity growth. They obtain results claiming that exit, entry and reallocation can explain one third of productivity growth in manufacturing since 1975 and all of the acceleration of productivity since 1985 (Maliranta et al., 2010). The study made in Finland differs from the Dutch in a few ways. The study by Bosma et al. (2011) studies dynamics in regions within the Netherlands using firm level data whereas Maliranta et al. use data for the entire country and they have plant level data in their use. With plant level data it is possible to observe entry and exit and especially resource allocation within firms, which is important in manufacturing sector where large companies dominate the market.

Another regional study by Marcus Dejardin (2011) tries to link net entry to economic growth in the regional level. In his study he describes firm entry as a *disequilibrating agent*, meaning that efficiency and innovations brought to market by an entrant will eventually mean that firms will also need to exit the market. Dejardin also points that firm entry and exit cannot always be definitely associated with Schumpeterian innovation processes. Firm exit may be caused by internal factors such as retirement of the entrepreneur or mismanagement issues. Also firm entry is not necessarily needed to set the innovative processes into motion because simply a threat of entry may be enough for incumbents to start improving their productivity. As in Bosma et al., 2011, Dejardin finds that there is positive effect between firm net entry and regional economic growth in the service sector. However, in manufacturing the relationship is either negative or autoregressive. (Dejardin, 2011.)

Creative destruction should also follow business cycles. In an efficient economy, the reallocation of resources should be concentrated on the times of recessions. During a recession, the opportunity cost of reallocation is low. Hence, ideally the job creation and destruction should be at the peak during the recessions. In reality, this may not be the case. Job destruction follows recessions and lead to increased unemployment, but job creation does not necessarily follow them. Wage rigidity and incomplete contracting can disrupt this cyclical response of creative destruction. (Caballero and Hammour, 1996.)

Threat of entry may have different effects in different sectors within an economy. One study by Aghion, Blundell, Griffith, Howitt and Prantl, 2009 obtained a result that the threat of technologically competitive entry provides incentives for incumbent firms to invest in innovations in industries that are close to the technological frontier. However, they also found that such a threat does not have positive effect on R&D investments in more laggard industries. (Aghion et al., 2009.)

## 2.2 Bias and missing prices in price indices

Constructing a price index is not a simple task. There are several possible sources of errors and bias. Price indices try to capture the price development of a representative basket of products. As it is not possible for statistical offices to follow the prices of every single product in the market, the basket is chosen by sampling. This already leads to the possible existence of sampling bias (International Monetary Fund, 2004).

The fixed basket of goods is also itself a source of bias. As time goes by, the once representative basket may not be representative anymore since new products have entered the market and tastes of consumers have shifted. This issue can be lessened by rotating the products in the basket more often. For example, the consumer price index in Finland used to be a fixed base index where the basket of goods was updated every five years. But since 2013, the CPI has been a chain index where the basket and weights are updated yearly (Statistics Finland, 2016).

Another possible source of bias is a change in relative prices. Statistics Finland uses modified Laspeyres index formula[1] to compute CPI and PPI. This formula does not take into account the fact that consumers tend to shift consumption from a product to another if their relative prices change. This bias is called substitution bias. (Statistics Finland, 2016.)

However, the emergence of new products and the changing quality of existing ones are the biggest challenges in the production of price indices. These issues are examined more in detail in the following subsections.

### 2.2.1 Issues with quality changes

Disappearing products are not the only thing that cause problems for the price indices. Existing products are developed constantly and new varieties enter the markets all the time. Price indices try to capture the pure price change of the products, that is, the change of quality adjusted price.

[1] Laspeyres index: $I_{t,0} = \frac{\sum_i p_{ti} q_{0i}}{\sum_i p_{0i} q_{0i}} \times 100$

However, when a new variety of a product replaces older one, some of the price change is probably due to the increased quality. Evaluating the magnitude of this quality change is one of the biggest challenges for the producers of price indices.

For example, Statistics Finland uses a few different methods to address these quality changes. As product is replaced by a new one, first thing to do is to ask whether the price for the new product is available also from earlier time period ($t-1$). In this way the actual quality-adjusted price change is captured. The second possibility is to ask for an expert evaluation. This means that the producer (or importer or another one who might have the information) of the product is asked to evaluate the magnitude of the quality growth so that it could be extracted from the price change. If neither of these options are available, the price development is imputed using the average price developments of other products within the same product class. (Statistics Finland, 2013.)

In practice, evaluating the magnitude of the quality change is a difficult task. It is known that quality changes are probably the biggest cause of bias in price indices. This issue was thoroughly examined in 1996 by so-called *Boskin Commission*, officially *the Advisory Commission to Study the Consumer Price Index* that was appointed to the task by the United States Senate. According to the commission, unmeasured quality growth leads to an upward bias of 0.6 percent per year in the CPI in the United States (while the total bias in the CPI was estimated to be 1.1 percent per year). The bias varies between different sectors within the economy. According to the commission, the biggest magnitude in the quality change bias occurs in medical care sector: 3.0 percent per year in 1970-1995. (Jorgenson, Boskin, Dulberger, Gordon and Griliches, 1996.)

The magnitude of quality growth has been also estimated for consumer durables in the United States. Mark Bils (2009) studied the quality growth for vehicles and consumer electronics and found out that two-thirds of the price changes associated with introduction of new models of the product should be allocated to quality growth. He also estimates that the quality growth has been understated and hence CPI inflation for durables has been overstated by 2 percentage point per year since 1988 (Bils, 2009). Bils and Klenow (2001) estimated that at least one-third of quality growth was incorporated into measured inflation in the United States, causing a bias of 0.8 percent per year in CPI consumer durables during 1980-1996 (Bils and Klenow, 2001).

Broda and Weinstein (2010) studied the consequences of creative destruction in price indices. They used scanner data on goods that cover around 40 percent of the CPI in the United States. Their findings suggest that the most of product creation and destruction is unobserved by the statistical office and that creative destruction leads to an upward bias in inflation measures. The bias averages between 0.6 and 0.9 percentage points per year. Another finding was that the bias is pro-cyclical and therefore business cycles would actually be more volatile than the official measures suggest (Broda and Weinstein, 2010). A more recent study by Hamano and Zanetti (2017) developed a general equilibrium model to study quality and variety bias in aggregate price level. They also found that the bias from new varieties is highly persistent and pro-cyclical. However, quality bias was found to become counter-cyclical in the long-run (Hamano and Zanetti, 2017).

### 2.2.2 Imputation of missing prices

Imputation is a widely used method for obtaining missing prices. While the use of imputation and its results may be questioned, there is some evidence that some imputation is better than no imputation at all as far as the quality of a index is concerned (Feenstra and Diewert, 2000). The magnitude of imputation is substantial. For example, in the United States 3 percent of products disappear from the market monthly in the CPI and the corresponding figure for PPI is 2 percent (Bils and Klenow, 2004 ; Nakamura and Steinsson, 2008). In addition to disappearing products, prices may be missing due to other reasons too. These reasons may include seasonal patterns in the production of the product or the informant has forgotten or ignored the price reporting task (Feenstra and Diewert, 2000).

There are several different ways how the missing prices can be imputed. Some of these were examined both theoretically and empirically by Feenstra and Diewert in their 2000 paper. As published official price indices in Finland are not revised the possible techniques are called 'long term cell mean' and 'short term cell mean' methods of imputation. Short term cell mean method derives the missing prices for the current period from the price developments from period $t-1$ to $t$ of other products within the same product category. Long term cell mean method, on the other hand, uses price development information from longer time interval in order to impute the missing prices. Feenstra and Diewert pointed out that use of long term cell mean method of imputation is as good as use of no imputation at all. Therefore, short term method is better (although not perfect) and that is the method also used in Finland and for example, in the United States. (Feenstra and Diewert, 2000.)

The method of imputation is based on a rather strong assumption that the price development of other products within the same product class is similar with the product whose price is not available. In some cases it may be so, but imputation will probably lead to a bias. The intuition behind the existence of the bias is the very idea of creative destruction: new producers replace old ones because they bring a new product with lower quality adjusted price to the markets. However, the imputation is based on those products that are not subject to creative destruction, meaning that their quality adjusted prices are likely to be higher than that of the new product. Therefore, use of imputation may lead to upward bias in inflation. That bias is often overlooked in the case of creative destruction and the paper by Aghion and others (Aghion et al., 2017) and this study try to quantify this bias.

### 2.2.3 Consequences of bias

No matter if the cause of bias is quality change, imputation or something else, over-estimation of inflation rate may have significant implications within the economy. Many contracts and rents are closely tied to the consumer price index, social benefits may have index adjustments and official GDP calculations often rely on the price indices. Consumer price index and cost-of-living index are examples of widely used indices in Finland. National pensions, student allowances, child benefits and rents of dwellings or land are usually tied to cost-of-living index. In addition, employment pension is tied to a index where CPI weighs 20% and earnings level 80% (Statistics Finland, 2016).

A good illustration on the importance of accurate CPI measures is made by Boskin and Jorgenson (1997). In the United States the upward bias in the CPI was estimated to be 1.1 percent per year since 1973 and 1.3 percent from 1979 to 1995. When calculating real average earnings using CPI, the earnings would have dropped by 13.5 percent from 1973 to 1995. However, if the bias is taken into account, the real average earnings have actually risen by 12.6 percent. Real median incomes have risen 35.7 percent instead of 4.3 percent calculated with biased CPI. In addition, real GDP growth have been understated by 0.5 percentage points per year. (Boskin and Jorgenson, 1997.)

Given the fact that price indices are an important tool in many areas of economy and society, it is crucial to recognize possible biases and short-comings in the production of these indices. *Boskin Commission's* final report was a remarkable contribution to the work of statistic offices. However, if there exists another sources of bias, it is important to find them and learn how big impact they might have on the accuracy of price statistics.

# 3 Model for missing growth

In their paper Aghion, Bergeaud, Boppart, Klenow and Li developed an accounting framework that enables the formulation of explicit expression for the missing growth. As the basis they use a growth model with exogenous innovation. Assumptions made in their paper are quite strong and one could question their relevance. Nevertheless, the model provides an interesting framework to study the possible consequences of imputation and creative destruction. This section introduces the theoretical basis of the Aghion et al., 2017 paper on which this study is built.

## 3.1 Aggregate economy and intermediate production

The model used in this study is a form of New Keynesian DSGE model. In the model, it is assumed that market for final goods is competitive, while producers of intermediate goods are monopolistic. First it is important to define the structure of the aggregate economy. When time is discrete, then in each period the economy's output is

$$Y = \left( \int_0^N [q(j)y(j)]^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

where $Y$ is the competitively produced output, $y(j)$ are intermediate inputs and $q(j)$ their quality. $N$ represents the possibly growing number of intermediate varieties that are available within the economy. The output of the economy has the constant elasticity of substitution (CES) structure. It is also assumed that intermediate inputs are produced one-for-one with labor and hence, the economic growth in this model is comparable also with productivity growth. (Aghion et al., 2017.)

In every period there is a constant amount of labour supplied by the households. Wage rate is the same in every firm. The expenditure by representative households on final goods is expressed by the budget constraint

$$M = PY, \tag{2}$$

where M is the nominal expenditure and P is the price index. In other words, the equation 2 implies that the aggregate nominal output equals the product of the price index and the real output.

In order to continue to build the growth model, the equilibrium prices of intermediate goods need to be defined. That equilibrium price for each intermediate good $j$ is

$$p(j) = \mu W, \forall j, \tag{3}$$

where $\mu > 1$ is a markup factor and $W = c(j)$ is the marginal cost. The markup is limited by a competitive fringe that the producers of intermediate goods are subject to. Therefore, profit maximizing monopolistic intermediate producer can optimally charge a markup factor of $\mu > 1$, where $\mu = \min\{\tilde{\mu}, \frac{\sigma}{\sigma-1}\}$. (Aghion et al., 2017.)

## 3.2 Innovation and technological change

Technological change induced by product innovation is the key source of economic growth in this model. It is assumed that every intermediate input $j$ faces an exogenous probability of creative destruction $\lambda_d \in [0, 1)$ in every period of time. This means that with the probability of $\lambda_d$ the incumbent firm producing the good $j$ is replaced by a new producer that can in turn be either an entrant or an incumbent firm. After the creative destruction happens, it is assumed that the new producer improves in quality compared to the old producer by a factor of $\gamma_d > 1$. It is important to point out that the previous producer cannot profitably produce the good $j$ anymore since Bertrand competition is assumed to exist within each product market. Therefore, the new producer can push the previous one out of the market. (Aghion et al., 2017.)

To be more precise the term *creative destruction* refers from now on to the innovation process where the producer of the good $j$ is replaced by a new producer. The quality change can be expressed as follows:

$$q_{t+1}(j) = \gamma_d q_t(j), \tag{4}$$

where $q_t(j)$ is the quality of the good $j$ at the point of time $t$. The innovation process where the producer does not change, but the quality of product is improved is referred as *incumbent own innovation*. In this case the quality change is expressed in a similar way with the creative destruction, but the factor by which the quality is changed is $\gamma_i$:

$$q_{t+1}(j) = \gamma_i q_t(j). \tag{5}$$

In addition to creative destruction and incumbent own innovation, there is a third possible source for growth: *new product varieties.* In order to determine how the quality of these new varieties can be compared to the existing ones, the changing number of intermediate inputs and firms needs to be defined. New firms are created on each period $t+1$, by number of $N_t\lambda_n$ and they sell a new product variety $\iota \in (N_t, N_{t+1}]$. The number of intermediate inputs at time period $t+1$ can be expressed as

$$N_{t+1} = (1+\lambda_n)N_t. \tag{6}$$

Now the quality of the new product variety can be stated with the help of the following assumption from Aghion et al., 2017:

**Assumption 1.** *A firm that introduces in period $t+1$ a new variety $\iota$ starts with a quality that equals $\gamma_n$ times the weighted geometric average of pre-existing varieties $j \in [0, N_t]$ in period $t$, or formally*

$$q_{t+1}(\iota) = \gamma_n \left( \frac{1}{N_t} \int_0^{N_t} q_t(j)^{\sigma-1} dj \right)^{\frac{1}{\sigma-1}}, \forall \iota \in (N_t, N_{t+1}]. \tag{7}$$

There are no restrictions for the value of $\gamma_n$ and therefore, the new product can enter the market with above or below average quality.

### 3.3 Missing growth and inflation

Using the equation 2, the real output growth from time period $t$ to $t+1$ can be written as

$$\frac{\widehat{Y_{t+1}}}{Y_t} = \frac{M_{t+1}}{M_t} \cdot \frac{\widehat{P_t}}{P_{t+1}}, \tag{8}$$

where $\widehat{\frac{P_t}{P_{t+1}}}$ is the inverse of the *measured* gross inflation rate. Furthermore, it is assumed that the growth in the nominal output $M_t$ is perfectly observed. This implies that the possible bias in the growth of real output is only due to mismeasurement of inflation. Hence, whenever there is over-estimation of inflation, there will also be positive missing growth. The rate of missing growth can be written using log first differences:

$$MG_{t+1} = \log\left(\frac{Y_{t+1}}{Y_t}\right) - \log\left(\frac{\widehat{Y_{t+1}}}{Y_t}\right) = \log\left(\frac{\widehat{P_{t+1}}}{P_t}\right) - \log\left(\frac{P_{t+1}}{P_t}\right). \tag{9}$$

To be able to compute the missing growth, an expression for the true inflation needs to be formulated. In their 2017 paper, Aghion, Bergeaud, Boppart, Klenow and Li derived a welfare-based aggregate price index which in turn can be used to obtain the expression for true inflation. The deriving of the true inflation can be seen from the following propositions. (For proofs, see Aghion et al., 2017.)

**Proposition 1.** *In equilibrium: (i) the demand for an intermediate product y(j) of quality q(j) sold at price p(j) is given by*

$$y(j) = q(j)^{\sigma-1}\left[\frac{P}{p(j)}\right]^{\sigma}\frac{M}{P}, \forall j. \tag{10}$$

*(ii) the equilibrium aggregate price index is given by*

$$P = \left(\int_0^N \left[\frac{p(j)}{q(j)}\right]^{1-\sigma} dj\right)^{\frac{1}{1-\sigma}}. \tag{11}$$

*Under optimal price setting of the firms we obtain*

$$P = \mu W\left(\int_0^N q(j)^{\sigma-1} dj\right)^{\frac{1}{1-\sigma}}. \tag{12}$$

**Proposition 2.** *The true gross inflation rate in the economy is given by*

$$\frac{P_{t+1}}{P_t} = \frac{W_{t+1}}{W_t}[1 + \lambda_d(\gamma_d^{\sigma-1} - 1) + (1-\lambda_d)\lambda_i(\gamma_i^{\sigma-1} - 1) + \lambda_n\gamma_n^{\sigma-1}]^{\frac{1}{1-\sigma}}. \tag{13}$$

In the proposition 2, the inflation rate is expressed as a function of the arrival rates and the step sizes of the different types of innovations. The formula includes a term for each type of innovation processes mentioned earlier. These terms capture the effect of the innovation type on inflation. (Aghion et al., 2017.)

Before obtaining the formula for the growth of missing output, it is essential to make the following assumption:

**Assumption 2.** *In the situation where a product leaves the market the statistical office resorts to imputation, that is, the set of products produced by surviving incumbent firms is assumed to be representative economy-wide.*

By using the assumption above and equations defined earlier, the expression for the growth of missing output can be derived and it is shown with the help of the following propositions (for proofs, see Aghion et al., 2017).

**Proposition 3.** *Under Assumption 2, the measured inflation rate can be written as*

$$\left(\widehat{\frac{P_{t+1}}{P_t}}\right) = \frac{W_{t+1}}{W_t}\left[1+\widehat{\lambda}_i(\widehat{\gamma}_i^{\,\sigma-1}-1)\right]^{\frac{1}{1-\sigma}}. \tag{14}$$

Now by combining equations 9, 13 and 14 the following formula for missing growth is obtained:

**Proposition 4.** *Missing real output growth is given by*

$$MG = \frac{1}{\sigma-1}\log\left[1+\frac{\lambda_d[\gamma_d^{\sigma-1}-1-\lambda_i(\gamma_i^{\sigma-1}-1)]+\lambda_n\gamma_n^{\sigma-1}}{1+\lambda_i(\gamma_i^{\sigma-1}-1)}\right]. \tag{15}$$

This formula will be the basis for the empirical part of this study, where the magnitude of the missing growth is estimated. More detailed description of the methods is given in the next section.

# 4 Methods and data

The magnitude of missing growth is estimated by a method that uses market shares of establishments in Finland. This method is referred as *the market share approach.* In addition, the sources of growth are estimated by a simulation model from Garcia-Macia et al., 2016. Simulation provides information about the possible sources of the growth that is potentially missed. This method is referred as *the indirect inference method.*

## 4.1 Statistics Finland data

Statistics Finland provides high quality data on Finnish firms. Establishment level data contains information for example on employment and revenue. It has been shown that most of the product creation and destruction happens within the firms and therefore, it is essential to use establishment level data (Broda and Weinstein, 2010). The availability of revenue data is a great asset and it allows even more accurate estimation of the market shares of establishments. Aghion et al., 2017 used establishment employment in order to evaluate the market shares because they did not have revenue data available outside manufacturing sector.

Data from firms in manufacturing is probably more accurate and precise also in Finland. However, data from other sectors should nevertheless be accurate enough in order to conduct this research. The data is available for the years 1982 - 2016 but until 1988 the data is only available in two year intervals. Therefore, only the data from years 1988 - 2016 will be used. The information about establishment's date of birth or date of closing is not available for every establishment. In these cases it is assumed that year of birth is the year when the establishment appears in the data for the first time. Similarly, the year of closing is assumed to be the last year when the establishment still exists in the data unless the establishment is still running in 2016.

In addition, the data is narrowed down by excluding some of the sectors of the economy. This is done in order to get comparable results with the United States and France where the data used included all private non-farm enterprises. Using industrial classification code (TOL 2008, see Appendix B) the sample is narrowed to include sectors B05 - N82 and P85 - S96. From now on, this interval is to be referred as 'whole economy'. Sectors that are excluded are agriculture, forestry, fishing, public administration, defence, activities of households as employers and activities of extraterritorial organizations. Table 1 provides some descriptive statistics for the used data set.

**Table 1:** Descriptive statistics

| | Establishments | Employment | Revenue |
|---|---|---|---|
| 1988 - 2016 | 249 038 | 6.0 | 1 038 275 |
| 1988 - 1997 | 181 735 | 7.9 | 823 198 |
| 1998 - 2007 | 262 246 | 5.4 | 1 069 390 |
| 2008 - 2016 | 309 142 | 4.6 | 1 242 675 |

**Note:** Table shows annual average number of establishments, annual average employment per establishment and annual average revenue per establishment.

For the market share approach, the required variables from the data are establishment id, revenue, years of start and end, employment and standard industrial classification code. These allow the examination of the missing growth from different points of view: market share can be calculated by revenue or by employment and in addition, using the classification code it is possible to study whether missing growth is varying between different sectors within the economy. Ideally the market shares should be calculated using product level data. This data is available in Finland only from the manufacturing sector. Due to classification issues it is not taken into consideration in this thesis. The second approach, the indirect inference method relies on the firm level data and exploits mainly the information on the job flows. Therefore, employment information is crucial for this method. Using the firm id, the same establishment level data used in the market share approach is aggregated to firm level. The aggregated data is then used to calculate figures describing firm dynamics. These figures are discussed more in detail later.

In both methods, the data for employment in establishments and firms is measured by headcount, not full time equivalent. Headcount is also used in the studies made in France and the United States and therefore, the usage of headcount allows for more comparable results between these countries.

## 4.2 Market share approach

The market share approach is based on the idea that market shares of different groups of products contain information about the quality-adjusted prices. In addition, the imputation method used by the statistical office assumes that the price development of the surviving products can be taken as representative for the entire economy. This is true if and only if the market shares of these products remain stable over time. Therefore, the market shares can be used to quantify the missing growth. (Aghion et al., 2017.)

### 4.2.1 Linking market shares to the missing growth

In order to show how the market share can be related to the model presented in the previous section, the market share of a product $j$ needs to be defined and it can be written as:

$$s(j) \equiv \frac{p(j)y(j)}{M}, \tag{16}$$

where $M = PY$, the aggregate nominal output. Now by combining equations 16 and 10, the market share of product $j$ is obtained as a function of quality-adjusted price relative to the aggregate price index $P$:

$$s(j) = \left(\frac{P}{p(j)/q(j)}\right)^{\sigma-1}. \tag{17}$$

According to the Aghion et al., 2017, this relationship holds also for the subset of products which is what the statistical office bases its imputation on. The products whose producers survive from time period $t$ to time period $t+1$ are called *continuers* and are denoted as set $\mathcal{I}_t = [0, \mathcal{N}_t] \setminus \mathcal{D}_t$, where $\mathcal{D}_t$ is the set of products that were creatively destructed. The growth rate of these continuers' market shares between two time periods can be expressed as

$$\frac{S_{I,t+1}}{S_{I,t}} = \left(\frac{P_{t+1}}{P_t}\right)^{\sigma-1}\left(\frac{W_{t+1}}{W_t}\right)^{1-\sigma}(1-\lambda_i+\lambda_i\gamma_i^{\sigma-1}). \tag{18}$$

Next another assumption is needed before formulating an expression for the missing growth as a function of market shares. It is assumed that statistical offices perfectly captures the quality improvements caused by incumbent own innovation, or more formally:

**Assumption 3.** *The statistical office perfectly observes the quality improvements due to incumbent own innovation. Hence,* $\widehat{\lambda}_i = \lambda_i$ *and* $\widehat{\gamma}_i = \gamma_i$.

Under assumption 3 and using the proposition 3 the market share of continuers can be expressed as

$$\frac{S_{I,t+1}}{S_{I,t}} = \left(\frac{P_{t+1}}{P_t}\right)^{\sigma-1} \left(\widehat{\frac{P_{t+1}}{P_t}}\right)^{-(\sigma-1)}. \tag{19}$$

As the continuers are exactly the group on which the imputation by statistical offices is based on, and the imputation results are valid if and only if the market share of those continuers remains stable, it can be seen from the equation 19 that whenever the market share decreases, the measured inflation $\widehat{\frac{P_{t+1}}{P_t}}$ is too high. Hence, there exists missing growth (given that $\sigma > 1$). Furthermore, the equation 19 together with the equation 9 can be used to get an expression which allows for the quantification of the missing growth (Aghion et al., 2017):

$$MG_{t+1} = \log\left(\widehat{\frac{P_{t+1}}{P_t}}\right) - \log\left(\frac{P_{t+1}}{P_t}\right) = \frac{1}{\sigma-1}\log\left(\frac{S_{I_t,t}}{S_{I_t,t+1}}\right). \tag{20}$$

The equation 20 is used to empirically study the magnitude of missing growth in Finland.

### 4.2.2 Measurement of the missing growth

The missing growth is estimated by using data from Statistics Finland. Required information contains establishment level data on private firms (excluding agricultural sector), their employment, revenue and the points of time when they have entered the market and left it.

The precise way the data will be used to estimate the market shares is as follows. Let $B$ denote the 'birth' and $D$ the 'death' of an establishment. $B$ refers to time period $t$ which is the first time the establishment enters the market and similarly $D$ refers to the last time period when the firm still exists in the data. Time period used is a calendar year. $I_t$ is the group of continuing establishments, that is, those who were born earlier than at $t$ and die in the period $t+1$ or later. In addition, $E_t$ is defined as the group of establishments that enter the market in $t$ and $X_t$ is defined as the group of establishments that exit the market between $t$ and $t+1$. The information about different establishment groups is presented in the following table. (Aghion et al., 2017.)

**Table 2:** Establishment groups used in market share calculations

| Group | Notation | Age |
|---|---|---|
| Incumbents | $I_t$ | $B < t, D \geq t$ |
| Entrants | $E_t$ | $B = t, D \geq t$ |
| Exits | $X_t$ | $B \leq t, D = t$ |

**Note:** B denotes the time of birth of the establishment and D denotes the last period of time when the establishment exists.

Now $L(t, G)$ represents the total employment or revenue of establishments belonging to the group $G \in$ ($I_t$, $E_t$ or $X_t$) in period $t$. Using $L(t, G)$, the market share ratio $\frac{S_{I_t,t}}{S_{I_t,t+1}}$ in the equation 20 can be calculated:

$$\frac{S_{I_t,t}}{S_{I_t,t+1}} = \frac{\dfrac{L(t, I_t)}{L(t, I_t) + L(t, X_t)}}{\dfrac{L(t+1, I_t)}{L(t+1, I_t) + L(t+1, E_{t+1})}}. \tag{21}$$

The obtained ratio of incumbent market share at time $t$ and at time $t+1$ can then be substituted into the equation 20 to obtain

$$MG = \frac{1}{\sigma - 1}\Bigg[\log\left(\frac{L(t, I_t)}{L(t, I_t) + L(t, X_t)}\right) - \log\left(\frac{L(t+1, I_t)}{L(t+1, I_t) + L(t+1, E_{t+1})}\right)\Bigg]. \tag{22}$$

Equation 22 expresses the missing growth with log difference of incumbent market shares. In order to study the possible causes of differences in missing growth magnitudes in different countries the equation 22 can be expressed in another way. By definition, the total market employment or revenue includes incumbents and exiting establishments at time $t$ and those same incumbents and entrants at time $t+1$. Therefore, if the market shares of exiting establishments at $t$ and entrants at $t+1$ are denoted by $S(X_t)$ and $S(E_{t+1})$ respectively, the equation 22 can be written as

$$MG = \frac{1}{\sigma - 1}\Bigg[\log\big(1 - S(X_t)\big) - \log\big(1 - S(E_{t+1})\big)\Bigg]. \tag{23}$$

In addition, if market shares of entrants and exiting establishments are small, the following approximation holds:

$$MG \approx \frac{1}{\sigma - 1}\big(S(E_{t+1}) - S(X_t)\big). \tag{24}$$

Differences in missing growth estimates therefore can be traced to firm dynamics. Whenever entrant market share at $t + 1$ exceeds that of exiting establishments at $t$, there will be missing growth. (Aghion et al., 2017.)

As Aghion and others state in their 2017 paper, the time period that is defined to be $B$ should be chosen with caution. The exact year when and establishment becomes operational will probably not give the right idea on about its production capacity, revenue and employment. Therefore, the $B$ will be defined as $B = B^d + k$, where $B^d$ is the year when the establishment appears in the data and $k \geq 0$ a certain number of years that will be added to the $B^d$. There is some evidence providing support for setting $k = 5$, since the first five years of firm's operation is usually the time interval when the firm grows the fastest (Haltiwanger, Jarmin and Miranda, 2013). The elasticity of substitution, $\sigma$, must also be defined. Hottman, Redding and Weinstein estimated cross-firm elasticities in their 2016 paper and median value was estimated to be 3.9 (Hottman, Redding and Weinstein, 2016). Based on their paper and on Aghion et al., 2017, $\sigma = 4$ is chosen to be the baseline value. Lower and higher values of both $k$ and $\sigma$ will, however, be examined.

## 4.3 Indirect inference

The second approach, the indirect inference method, estimates the model parameters (quality step sizes and arrival rates of innovation) in order to provide information on whether the growth that is potentially missed comes from incumbent producers or entrants. Although the method of indirect inference is not as intuitive as the market share approach, it has a few advantages. First it allows firms to have several different products. It also removes the restriction that creative destruction is only brought by entrants. Therefore, also incumbent producers can innovate and creatively destruct other products.

### 4.3.1 Simulation algorithm

The algorithm used to estimate the arrival rates and step sizes was first developed by Garcia-Macia, Hsieh and Klenow (GHK) in 2016. In their model, firm employment is assumed to be the outcome of three types of innovation: creative destruction (CD), incumbent own innovation (OI) and new products varieties (NV). The intuition behind the GHK algorithm is that firm's employment is proportional to the quality of the products and the number of product varieties. When a firm successfully improves the quality of its products or manages to innovate a new variety, its employment will grow. On the other hand, when another firm enters the market with better quality products or new varieties, the incumbents employment will shrink. (Garcia-Macia et al., 2016.)

In order to estimate the step size and arrival rate of the three innovation types, GHK estimates these parameters to fit aggregate total factor productivity (TFP) growth. After that, the growth is decomposed into four: new varieties, incumbent own innovation, creative destruction by incumbents and creative destruction by entering firms.

This method was also applied in the paper Aghion et al., 2017. In that paper, the authors modified the algorithm to measure the missing growth. They rely on the assumption that statistical offices perfectly observe the step sizes and arrival rates of incumbent own innovation. However, this is not the case in reality. Therefore, in this study the original algorithm is used. The gathered information may help statistical offices to decide whether they should focus on keeping up with incumbent innovation or to try to recruit new entrants into the production of price indices.

The equation for the TFP growth in the original GHK algorithm can be expressed using notations of this study:

$$1+g = [(1-\delta_o\psi)\left\{[\lambda_i(1-\lambda_{e,d}-\lambda_{i,d})+(\lambda_{e,d}+\lambda_{i,d})](\gamma_i^{\sigma-1}-1)+1\right\}+(\lambda_{i,n}+\lambda_{e,n})\gamma_n^{\sigma-1}]^{\frac{1}{\sigma-1}}, \quad (25)$$

where $\delta_o$ is the share of products in the previous time period that have quality fallen below the obsolescence cutoff, $\psi$ denotes the average quality of those products below the cutoff relative to the average quality. $\delta_o$ and $\psi$ come from the assumption in the GHK model: product exit is endogenous. This means that firms drop the products whose quality relative to the average quality is below a certain cutoff. In addition $\lambda_{e,d}$ is the share of non-obsolete products with entrant creative destruction, $\lambda_{i,d}$ is the share of non-obsolete products with incumbent own creative destruction, $\lambda_{i,n} + \lambda_{e,n}$ is the sum of new varieties from incumbents and entrants relative to the mass of products in the previous period and finally $\gamma_i$ and $\gamma_d$ are the step sizes of own innovation and creative destruction. The model used in GHK paper differs slightly from the one presented earlier in this paper. GHK endogenize the product exit with the cut-off quality and they draw quality step sizes from Pareto distribution instead of having a fixed step size. Otherwise the working mechanics of these two models are similar. (Aghion et al., 2017.)

The simulation algorithm follows a procedure of simulated method of moments (SMM). The needed data moments are then calculated from this simulated sample and they are matched to the real world data to obtain estimates for the needed parameters (Garcia-Macia et al., 2016). The idea behind the simulation algorithm is to simulate life paths of large number of firms. Measured growth and minimum employment are set to exactly fit the TFP growth rate and minimum employment of 1 from the data. The rest moments from data and simulation are chosen so that the mean squared percentage distance between simulated and real data moments is minimized. For more detailed description for the simulation algorithm, see Garcia-Macia et al., 2016.

#### 4.3.2 Data moments

Required data moments for the simulation are:

- TFP growth rate
- Aggregate employment growth rate
- Employment share of entrants
- Job creation and destruction rates
- Standard deviation of log employment across firms
- Share of job creation where employment growth $\leq 1$
- Minimum firm employment

These 8 data moments are used to infer 8 parameter values for step-sizes and arrival rates of different types of innovations. The simulation is run for two different samples. First for the years 1993-2003 and second for 2003-2013. The simulation model assumes that one period is 5 years and therefore, the data moments are calculated to match this assumption.

# 5 Results

## 5.1 Market share approach

Missing growth due to creative destruction and use of imputation is not as high in Finland as it is in the United States. This is to some extent an expected result. On average, the missing growth calculated with revenue data was 0.489 percentage points per year during 1989-2016. Using the employment data, the missing growth was 0.385 percentage points per year during 1989-2016. These results are presented in Table 3 below. The TFP growth measured by the Statistics Finland for the same time period was 1.153 percent per year. Given the estimates for the missing growth, approximately 25 to 30 % of growth has been missed annually since 1988.

Table 4 presents the estimates for the missing growth in different time periods. Missing growth has been lowest during the period 1989 - 1998 and highest during the years 1999 - 2008. However,

**Table 3:** Estimates for the missing growth, average 1989-2016

| | Missing Growth | Measured Growth | Actual Growth | % of Growth Missed |
|---|---|---|---|---|
| Revenue | 0.489 | 1.153 | 1.642 | 29.8 |
| Employment | 0.532 | 1.153 | 1.685 | 31.6 |

**Note:** Table reports estimates for the missing growth, TFP growth measured by Statistics Finland, actual growth where missed growth is added to the measured growth and share of true growth missed according to estimates.

using the employment data the period from 2009 to 2016 had the highest rate of missing growth. Finland faced a severe depression in the first half of 1990s which could be one factor explaining the lower missing growth estimates. The high rates of missing growth during 1999 - 2008 could be originating from the information technology boom and rise of telecommunication sector in Finland.

**Table 4:** Estimates for the missing growth for different time periods

| | Missing Growth (Revenue) | Missing Growth (Employment) |
|---|---|---|
| 1989 - 2016 | 0.489 | 0.532 |
| 1989 - 1998 | 0.341 | 0.284 |
| 1999 - 2008 | 0.647 | 0.624 |
| 2009 - 2016 | 0.477 | 0.734 |

**Note:** Missing growth estimates are annual averages and in percentage points per year.

Figure 1 presents yearly estimates and linear trend lines on a scatter plot for missing growth computed with both revenue and employment data. As it can be seen the estimates for missing growth form a cyclical pattern with both employment and revenue data. Especially the depression of 1990s can be seen in the graphs as low and even negative values for the missing growth. This may support the idea of the bias being pro-cyclical. On the other hand, the financial crisis of 2008 have not had effect on the missing growth values at similar scale.

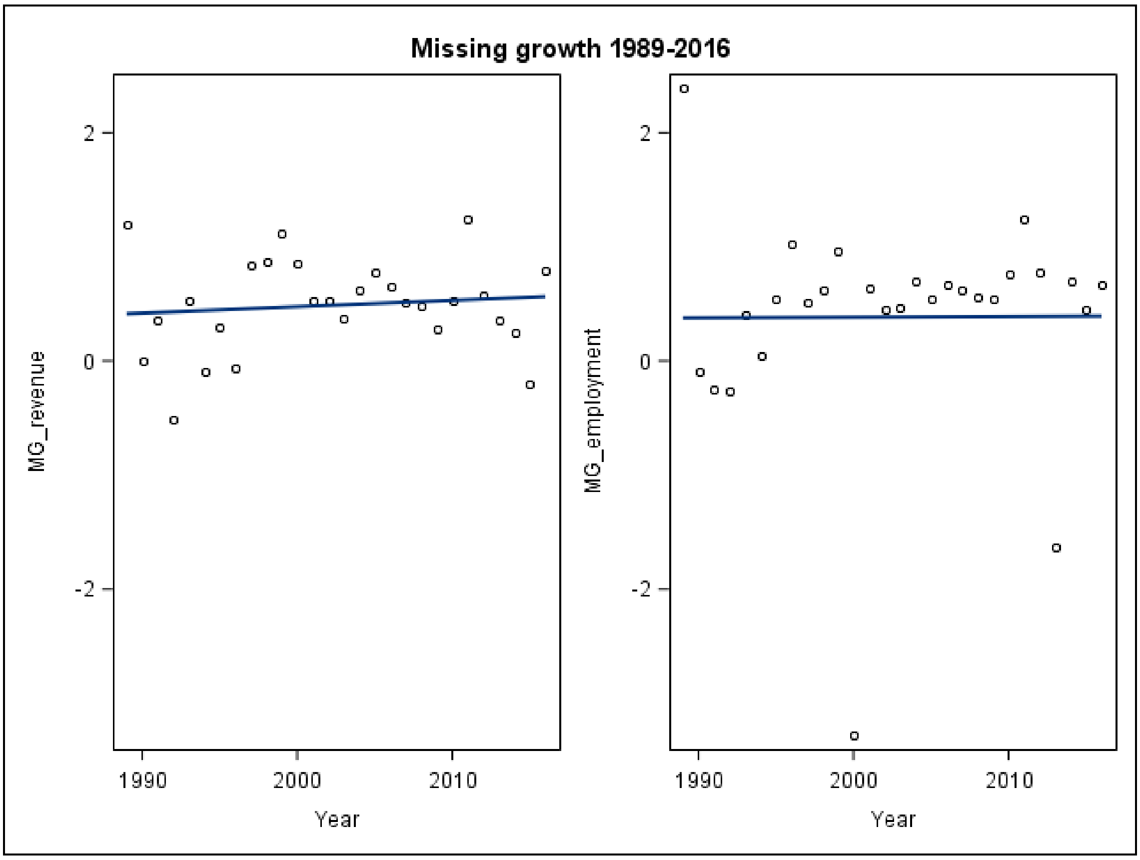


**Figure 1:** Missing growth 1989-2016 with revenue and employment data

Another observation can be made from the Figure 1. Missing growth calculated with employment data seems to have three significantly large outliers. When these three data points are included in the calculations, the mean missing growth for 1989-2016 with employment data becomes 0.385. This is significantly lower than the magnitude of missing growth in the United States and France. Missing growth for different time periods with large outliers included in calculations can be seen in the Appendix D.

### 5.1.1 Missing growth in different sectors

Using the industrial classification codes it is possible to calculate missing growth for different sectors within the economy. Table 5 provides the missing growth estimates for a few chosen sectors. The table reports the baseline results for the whole economy and estimates for missing growth in sectors of manufacturing, wholesale and retail trade, information and communication and finally professional, scientific and technical activities.

**Table 5:** Missing growth in different sectors 1989-2016

| | Missing Growth (Revenue) | Missing Growth (Employment) |
|---|---|---|
| Whole economy | 0.489 | 0.532 |
| Manufacturing | 0.003 | 0.075 |
| Wholesale and retail trade | 0.488 | 0.551 |
| Information and communication | 1.466 | 1.265 |
| Professional, scientific and technical activities | 1.741 | 0.989 |

**Note:** Estimates are annual averages and in percentage points per year. Sectors are determined by corresponding TOL 2008 classification codes (see Appendix B).

It seems that missing growth in manufacturing sector is small. This result is in line with results from the United States and France (Aghion et al., 2017; Aghion, Bergeaud, Boppart and Bunel, 2018). Manufacturing is one sector in which imputation is commonly used in producer price indices in Finland and therefore, the small magnitude of the missing growth is a reassuring result. Missing growth in the sector of wholesale and retail trade fits quite well into the mean of whole economy.

On the other hand, results for information and communication and professional, scientific and technical activities are three or four times larger than the average estimates for the whole economy. Information and communications sector includes telecommunication and computer programming activities and those are branches that have faced a lot of development and probably creative destruction in the given time period. Therefore, it is not a surprise that the magnitude of missing growth is above average. However, the results of 1.5 and 1.3 (rounded) percentage points per year are significantly large. Professional, scientific and technical activities includes for example scientific research and development and architectural and engineering activities that all are branches that certainly have been subject to creative destruction as technology has developed rapidly from 1990s to 2010s. As in ICT sector, the estimates are very high: 1.74 and 0.99 percentage points per year, computed with revenue and employment data respectively.

Figure 2 shows scatter plots and linear trend lines of yearly missing growth estimates for the whole economy, manufacturing, wholesale and retail trade and information and communication sectors. It can be seen that missing growth has been quite stable over the years for manufacturing and retail trade whereas estimates for information and communication sector have more spread and the linear fit shows a declining trend in the missing growth.

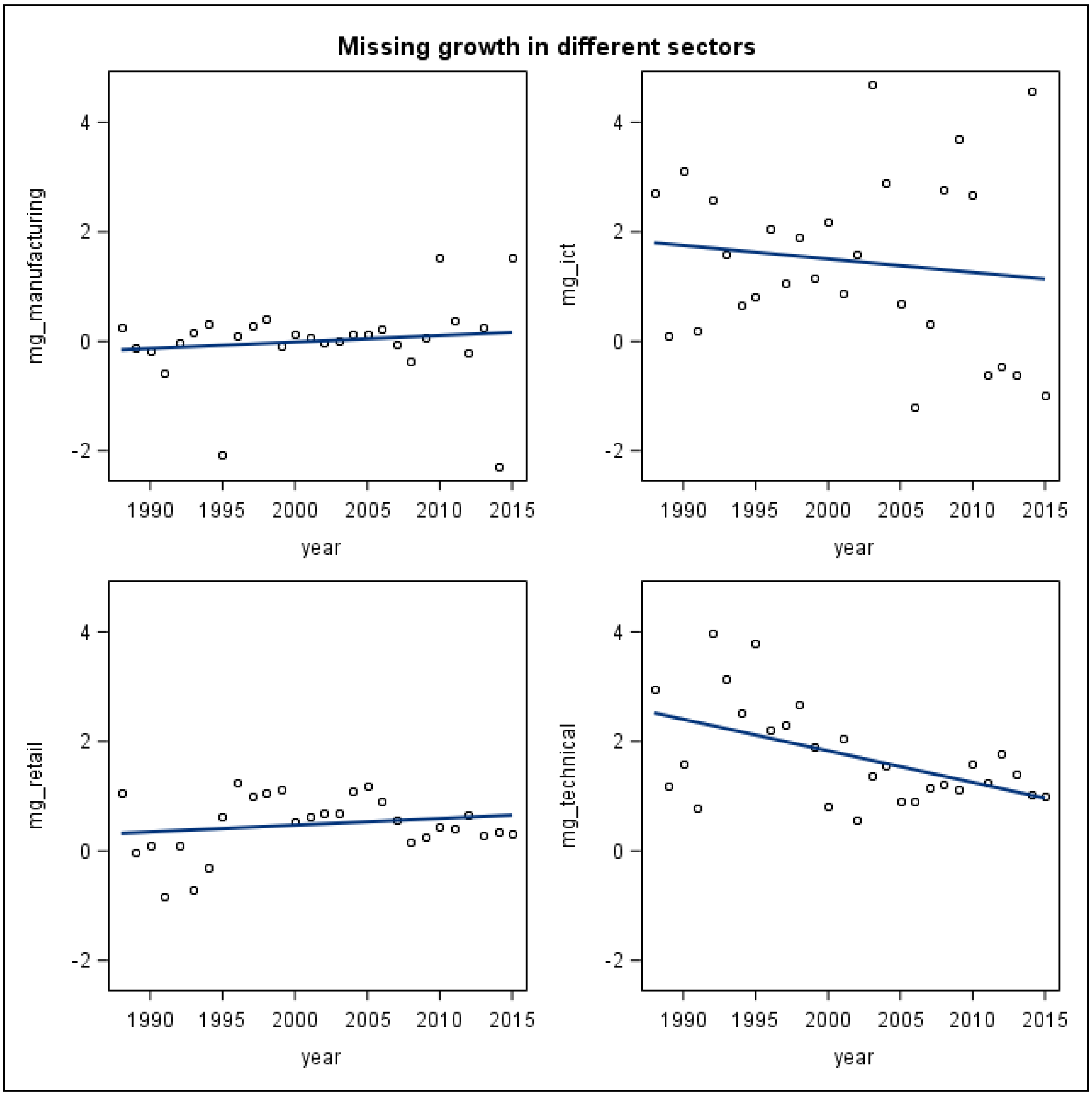


**Figure 2:** Missing growth in different sectors 1989-2016, using revenue data

Missing growth estimates for other sectors can be found from the Appendix C. All in all it seems that there are large variability between different sectors. The estimates can differ drastically even within the same sector when comparing the results obtained with revenue and employment data. Missing growth is largest in the sector of human health and social work activities, 1.935 percentage points per year with revenue data. On the other hand, with employment data the largest missing growth is found from the sector of real estate activities, 1.469 percentage points per year.

### 5.1.2 Different lag and elasticity of substitution

In the baseline calculations the lag for establishment age was set to 5 and elasticity of substitution to 4, following the paper by Aghion et al., 2017. As a robustness check, the missing growth is computed also with different values for $k$ and $\sigma$. Table 6 presents results for different values for the lag of establishment age k. As it can be seen from these results, the magnitude of the missing growth seems to get larger as the lag $k$ is increased. The difference between estimates computed with employment data and revenue data is decreasing as $k$ get larger.

**Table 6:** Missing growth with different values of lag k

| | k = 1 | k = 3 | k = 5 | k = 7 |
|---|---|---|---|---|
| Revenue | 0.196 | 0.397 | 0.489 | 0.606 |
| Employment | 0.253 | 0.454 | 0.532 | 0.590 |

**Note:** Values are percentage points per year and averages for time period 1989-2016. $\sigma = 4$ has been kept unaltered.

The result are not surprising. As establishment gets older, usually its employment and revenue grow with age. Therefore, older the establishment classified as entrant, the bigger the missing growth estimate. The development of revenue and employment with age of the establishment can be seen from the Figure 3 below.

Table 7 presents missing growth estimates for different values for elasticity of substitution $\sigma$. When $\sigma = 2$ the missing growth is 1.467 calculated with revenue and 1.348 with employment data. As $\sigma$ is increased, the magnitude of missing growth steadily decreases and the difference between revenue results and employment results decreases.

**Table 7:** Missing growth with different values of $\sigma$

| | $\sigma = 2$ | $\sigma = 3$ | $\sigma = 4$ | $\sigma = 5$ | $\sigma = 6$ |
|---|---|---|---|---|---|
| Revenue | 1.467 | 0.734 | 0.489 | 0.367 | 0.293 |
| Employment | 1.348 | 0.674 | 0.532 | 0.337 | 0.313 |

**Note:** Entries are percentage points per year and averages for time period 1989-2016. The lag $k = 5$ has been kept unaltered.

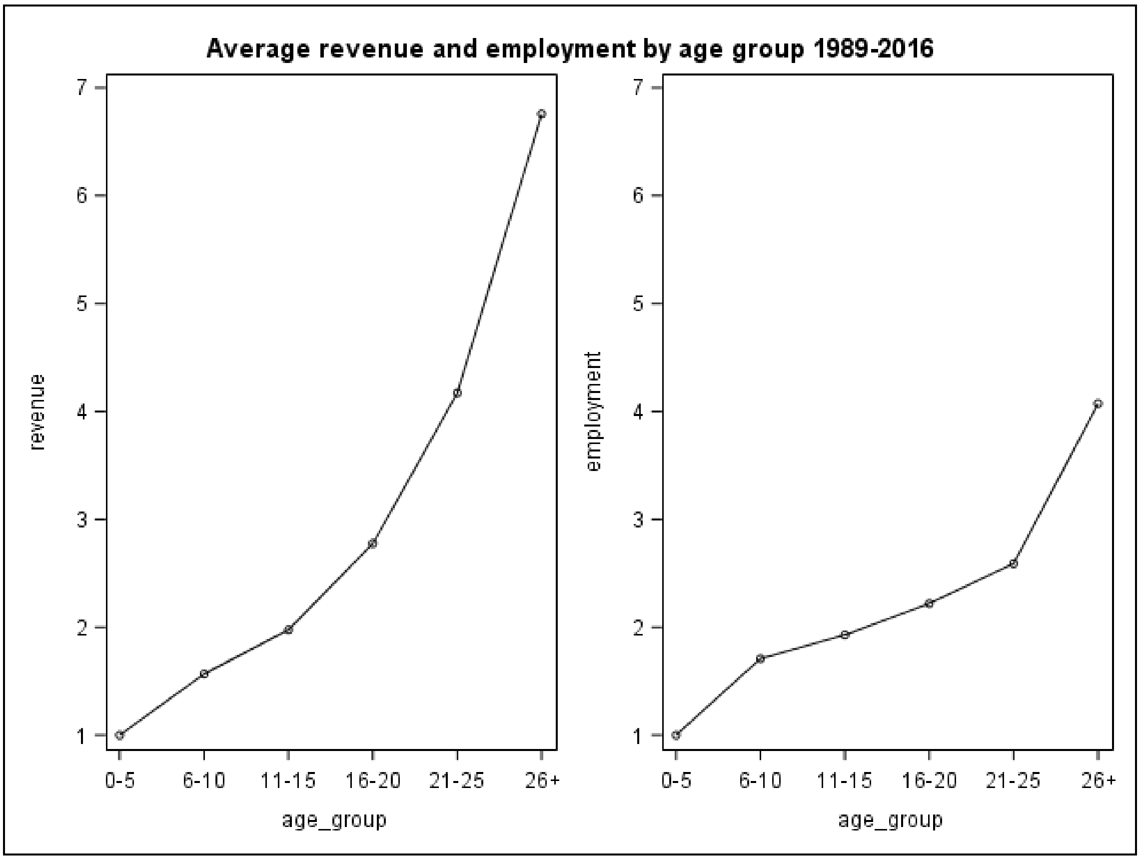


**Figure 3:** Size of an establishment by age. Values are normalized so that the employment/revenue of the youngest age group is equal to 1.

All in all it seems that the missing growth estimate is usually larger when using revenue data to compute the market shares. Often the yearly estimates for missing growth are also more volatile with revenue data. This can be explained by the faster reactions of revenue to the situation in the markets. Due to regulations in labour markets, employment in establishment do not necessarily react to market shocks so fast. This is the case especially when when revenue is falling and the number of employees should be reduced.

#### 5.1.3 Results from other countries

As it has been mentioned missing growth has been examined also in the United States and France, using the same methodology as in this study. Results from Finland are comparable in magnitude with the results from the other two countries. Following table presents the results from all three countries, computed with employment data. The corresponding estimate for missing growth computed with revenue data is also presented in the table in parentheses.

The most surprising result is that the missing growth seems to be the largest in Finland during the period of years 1996 to 2005. The magnitude of the missing growth was 0.66 which is 0.11 percentage points larger than in the United States and almost double in size when compared to France. This implies that there has been significantly different dynamics concerning exiting and entering establishments in Finland compared to the other countries.

On the period of years 2006 to 2013 the magnitude of missing growth in Finland was 0.74. This equals the estimate from the United States. In France the corresponding estimate was 0.60. It seems that the missing growth was higher in all countries during the period of 2006-2013 when compared to the years 1996-2005.

Given time periods included significant outliers in Finnish results and these outliers have been taken out from the computation of the results on the Table 8. The magnitude of missing growth was drastically smaller in Finland when the outliers were not taken out from the calculations. The results without omitting the outliers can be found from the Appendix D.

**Table 8:** Missing growth in Finland, France and the United States

| | Missing growth (FIN) | Missing growth (FRA) | Missing growth (USA) |
|---|---|---|---|
| 1996 - 2005 | 0.66 (0.65) | 0.38 | 0.55 |
| 2006 - 2013 | 0.74 (0.58) | 0.60 | 0.74 |

**Note:** Entries are percentage points per year and they are calculated with employment data. Results for France and USA are from Aghion, Bergeaud, Boppart and Bunel, 2018 and Aghion, Bergeaud, Boppart, Klenow and Li, 2017.

Where do the differences between countries come from? The magnitude of missing growth depends on the market share of incumbent firms. The smaller the share of period $t+1$ compared to the share of period $t$, the larger the missing growth. The market share of incumbents in turn depend on the entrants and exiting firms. If the market share of entrants exceeds that of the exiting firms, then it is expected that the market share of incumbents will fall.

In order to get the idea what could have been different in Finnish economy in terms of firm dynamics compared to France and USA, one must look into the employment and revenue of entrants and exiting firms. The following table presents market shares of entering and exiting establishments.

Table 9 presents the market shares of exiting establishments at time period $t$ and that of entrants at time period $t+1$. As it can be seen from the equation 24, the difference between entrant share and exit share can be used as an approximation about the missing growth. The relative sizes of entry share compared to the exit share are similar in all three countries. This is the reason why missing growth estimates are also similar in magnitude in these countries. However, it does not

**Table 9:** Market shares of exiting and entering establishments 2006-2013

| | Exit share | Entry share |
|---|---|---|
| France | 6.5 % | 8.2 % |
| United States | 3.3 % | 5.1 % |
| Finland | 1.9 % | 4.0 % |

**Note:** Entries are mean percentage shares per year and are based on the market shares calculated with employment data.

mean that the entry and exit rates have to be similar. Also the volumes of entering and exiting firms probably differ drastically between Finland and the United States for example.

## 5.2 Method of indirect inference

The model parameter values for arrival rates for different types of innovation are presented in the Table 10. The results show that for the sample 1993–2003 incumbents' own innovations that improve their own varieties arrive at the rate 63.3% per period. Improvements through creative destruction by other incumbents conditional on no own innovation arrive at the rate of 28.9% per period. Given that there are no incumbent own innovation or creative destruction by other incumbents, creative destruction by entrants occurs with the probability of 1. Unconditional probability for creative destruction by incumbents is given by

$$(1 - 0.633) \times 0.289 = 0.106 = 10.6\%. \tag{26}$$

Similarly, the unconditional probability for creative destruction by entrants can be computed by

$$(1 - 0.633) \times (1 - 0.289) = 0.261 = 26.1\%. \tag{27}$$

Therefore, a product is improved in every period with probability of 100% from which 63.3% is due to incumbent own innovation and the rest 36.7% is due to creative destruction.

The unconditional probability for creative destruction by incumbents in the sample 2003–2013 is given by

$$(1 - 0.679) \times 0.331 = 0.106 = 10.6\%. \tag{28}$$

And the unconditional probability for creative destruction by entrants in 2003–2013 was

$$(1 - 0.679) \times (1 - 0.331) = 0.215 = 21.5\%. \tag{29}$$

Hence, product improvements happened due to incumbent own innovation in 67.9% of the cases and the rest 32.1% were due to creative destruction.

New varieties were produced by both incumbents and entrants with the rates of 3.6% and 2.1% per period respectively in 1993–2003. The corresponding figures for the period 2003–2013 can be seen from the second column of the Table 10.

**Table 10:** Inferred parameter values for arrival rates

| | 1993-2003 | 2003-2013 |
|---|---|---|
| Creative destruction, incumbents | 28.9 % | 33.1 % |
| Creative destruction, entrants | 100 % | 100 % |
| New varieties, incumbents | 3.6 % | 1.4 % |
| New varieties, entrants | 2.1 % | 0.0 % |
| Incumbent own innovation | 63.3 % | 67.9 % |

**Note:** Entries are probabilities.

Table 11 shows the effect of innovation on the quality of the product. It also shows the cutoff quality threshold. If the quality of new variety or innovated product remains under that threshold, it will fall off the market. When a product was improved either through incumbent own innovation or creative destruction in 1993–2003, its quality became on average 1.12 times larger than the average quality of existing products. In 2003–2013 the corresponding coefficient was 1.01. New product varieties reached the quality of 33% and 31% of average quality of existing products in 1993–2003 and 2003–2013 respectively. The obsolescence cutoff was 3% in both samples. The overhead cost, $\delta_o$, was 2.1% in 1993–2003 and 0.006% in 2003–2013. The overhead cost gives the share of products that fall below the obsolescence cutoff.

**Table 11:** Relative qualities of innovated products

| | 1993-2003 | 2003-2013 |
|---|---|---|
| Creative destruction and own innovation | 1.12 | 1.01 |
| New varieties | 0.33 | 0.31 |
| Cutoff quality | 0.03 | 0.03 |

The most important results from the simulation for this paper are the contributions of different innovations to growth. Given that some of the growth is missed as shown in the market share approach, it would be crucial to have information on the channels of growth in order to deal with the bias.

The contributions are listed in the Table 12 below. In both periods, the contribution by incumbent own innovation is the highest: 59.27% in 1993–2003 and 57.79% in 2003–2013. Contribution of creative destruction in 1993–2003 was 36.14% from which 25.55% was by entrants. Corresponding figures for the sample 2003–2013 were 27.43% and 18.35%.

As the majority of growth and possibly therefore the missed growth is induced by incumbent own innovation it would be easier for statistical offices to observe. As the sample of price indices cannot be updated constantly, the entrants are not included in the calculations. Information of product improvements of existing products that are already part of the indices can be taken into account. Nevertheless, roughly one third of the growth is induced by creative destruction which will be problematic as far as price indices are concerned.

**Table 12:** Contributions to growth

| | 1993-2003 | 2003-2013 |
|---|---|---|
| Creative destruction, incumbents | 10.59 % | 9.08 % |
| Creative destruction, entrants | 25.55 % | 18.35 % |
| New varieties, incumbents | 3.00 % | 14.72 % |
| New varieties, entrants | 1.59 % | 0.06 % |
| Incumbent own innovation | 59.27 % | 57.79 % |

**Note:** Entries are percentage shares.

### 5.2.1 Model Fit

Tables 13 and 14 show the model fit, that is, comparison of data moments and their equivalents from the simulated model. The root mean squared error was 5.62% in the sample 1993–2003. It can also be seen that apart from employment growth rate, the moments match quite well between the data and the model.

**Table 13:** Model fit, 1993-2003

| | Data | Model |
|---|---|---|
| Employment share of entrants | 30.9 % | 28.1 % |
| Employment growth rate | 3.5 % | 0.7 % |
| Job creation rate | 45.8 % | 45.8 % |
| Job destruction rate | 42.2 % | 42.3 % |
| Share of job creation $< 1$ | 16.7 % | 18.4 % |
| Standard deviation of log employment | 1.10 | 1.21 |
| Root mean squared error | | 5.62 % |

The root mean squared error in the sample of 2003–2013 was significantly higher than in the previous sample, 31.7%. As it can be seen from the Table 14, the share of firms that have job creation below 1 did not match very well in the model. When comparing the data moments between these two samples, the key difference was the TFP growth rate. In the sample 1993–2003 it was 2.3% whereas in the sample 2003–2013 it was only 0.2%. As the simulation forces the TFP growth to match the data, a low growth rate may then have affected the simulation negatively.

**Table 14:** Model fit, 2003-2013

| | Data | Model |
|---|---|---|
| Employment share of entrants | 22.6 % | 21.5 % |
| Employment growth rate | 1.3 % | 0.3 % |
| Job creation rate | 37.9 % | 32.4 % |
| Job destruction rate | 36.5 % | 31.0 % |
| Share of job creation $< 1$ | 21.7 % | 8.9 % |
| Standard deviation of log employment | 1.11 | 1.33 |
| Root mean squared error | | 31.7 % |

# 6 Conclusions

The aim of this thesis was to use Schumpeterian growth model and methodology developed by Aghion et al., 2017 and determine whether imputation in price indices by the statistical office in the case of creative destruction leads to a bias in inflation and hence, TFP growth measures. The research question was approached with two different methods. Market share approach tried to estimate the magnitude of the missing growth in Finland. The indirect inference method on the other hand estimates the arrival rates and step sizes of different types of innovations in order to decompose the potentially missed growth into its components: creative destruction, incumbent own innovation and new product varieties.

Results from the market share approach suggest that Finland has faced missed growth by 0.489 percentage points per year on average during the years 1988-2016 based on the calculations made with revenue data. Corresponding result with employment data was 0.532 percentage points per year. These results are surprisingly similar with those from the United States, suggesting that the market share of incumbent establishments have decreased steadily at similar rate in both countries.

Assuming the estimates are correct, several implications can be drawn. All contracts, rents and social benefits and pensions that are tied to inflation rate should have risen more during these years. In addition, if the magnitude of missing growth is similar in the whole euro-area, the European Central Bank should consider targeting the true quality-adjusted inflation rate, that is, approximately 0.5 percentage points higher than usually.

Statistical offices provide these inflation and growth measures in many countries. It would be extremely hard to obtain as accurate data as it would require to overcome the bias. Ideally, that would mean data for entering and exiting *products* and perfect information about quality improvements made by incumbents on the existing products. As suggested also in Aghion et al., 2017, some sort of hedonic estimation may be more realistic aim to reach. Imputation should be based on the direct quality adjustments made by the statistical offices for the incumbent products that have been improved.

However, the model used in this thesis has a lot of assumptions and limitations that may not be realistic and therefore, one should be cautious with the results of this paper.

The results from the indirect inference method suggested that most of the growth is induced by incumbent own innovation, roughly two thirds. This is valuable information for statisticians computing producer or consumer price indices. Information of the quality improvements can be obtained from the incumbent producers and therefore bias in growth induced by them should be lower.

However, a large share of the growth still is coming from creative destruction both by incumbents and entrants. As the sample of price indices are often updated in 5 year intervals, the entrants effect will not be part of the indices. Annual chain linked index will certainly lower the bias as the sample is updated yearly and this method has been taken into use in Finnish CPI and PPI.

Sources and magnitudes of bias in price indices has been studied a lot, and this paper contributes to that field. The sources are quite well known but the problem usually is finding tools to overcome such a bias. Imputation together with creative destruction is being studied in several countries and more research should in future be concentrated in finding a way to lower the bias as inflation and growth are in the center of political decision making.

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# Appendices

## A Notations

Following table presents symbols used in this study and their meanings.

**Table 15:** Notations used in the model

| Notation | Interpretation |
|---|---|
| $\lambda_d$ | Arrival rate of creative destruction |
| $\lambda_i$ | Arrival rate of incumbent own innovation |
| $\lambda_n$ | Arrival rate of new varieties |
| $\gamma_d$ | Quality step-size of creative destruction |
| $\gamma_i$ | Quality step-size of incumbent own innovation |
| $\gamma_n$ | Quality step-size of new variety |
| $\sigma$ | Elasticity of substitution |
| $I_t$ | Incumbent firms at time period t |
| $E_t$ | Entrants at time period t |
| $X_t$ | Exiting firms at time period t |

# B TOL 2008 Industrial Classification

TOL 2008 classification codes are included in the establishment level data set. Following table provides description of the classification system.

**Table 16:** TOL 2008 Classification used by Statistics Finland

| TOL 2008 Code | Description |
|---|---|
| A (01 - 03) | Agriculture, forestry and fishing |
| B (05 - 09) | Mining and quarrying |
| C (10 - 33) | Manufacturing |
| D (35) | Electricity, gas, steam and air conditioning supply |
| E (36 - 39) | Water supply; sewerage, waste management and remediation activities |
| F (41 - 43) | Construction |
| G (45 - 47) | Wholesale and retail trade; repair of motor vehicles and motorcycles |
| H (49 - 53) | Transportation and storage |
| I (55 - 56) | Accommodation and food service activities |
| J (58 - 63) | Information and communication |
| K (64 - 66) | Financial and insurance activities |
| L (68) | Real estate activities |
| M (69 - 75) | Professional, scientific and technical activities |
| N (77 - 82) | Administrative and support service activities |
| O (84) | Public administration and defence; compulsory social security |
| P (85) | Education |
| Q (86 - 88) | Human health and social work activities |
| R (90 - 93) | Arts, entertainment and recreation |
| S (94 - 96) | Other service activities |
| T (97 - 98) | Activities of households as employers |
| U (99) | Activities of extraterritorial organisations and bodies |
| X (00) | Industry unknown |

**Note:** Table shows TOL 2008 industrial classification codes on level 1 (alphabetical) and corresponding two-digit level 2 codes and descriptions. TOL 2008 is Finland's national version of the NACE Rev. 2 classification system.

# C Missing growth estimates for different sectors

**Table 17:** Missing growth in different sectors 1989-2016

| Sector | Missing growth (revenue) | Missing growth (employment) |
|---|---|---|
| Mining and quarrying | 0.990 | 0.960 |
| Manufacturing | 0.003 | 0.075 |
| Electricity, gas, steam | 1.261 | 0.419 |
| Water supply, waste managements and sewage | 1.015 | 0.763 |
| Construction | 1.011 | 1.173 |
| Whole sale and retail trade | 0.488 | 0.551 |
| Transportation and storage | 0.703 | 0.590 |
| Accomodation and food service activities | 1.203 | 1.064 |
| Information and communication | 1.466 | 1.265 |
| Financial and insurance services | 0.972 | 0.107 |
| Real estate activities | 1.828 | 0.722 |
| Professional, scientific and technical activities | 1.741 | 0.989 |
| Administrative and support service activities | 1.407 | 1.469 |
| Education | 1.373 | 0.563 |
| Human health and social work activities | 1.935 | 1.147 |
| Arts, entertainment and recreation | 0.368 | 0.874 |
| Other service activities | 1.037 | 0.681 |

**Note:** Entries are percentage points per year. Unusually large outliers have been omitted from the calculations. Sectors are computed with TOL 2008 industrial classification.

# D Additional figures and tables

**Table 18:** Estimates for the missing growth for different time periods

| | Missing Growth (Revenue) | Missing Growth (Employment) |
|---|---|---|
| 1989 - 2016 | 0.489 | 0.385 |
| 1989 - 1998 | 0.341 | 0.494 |
| 1999 - 2008 | 0.647 | 0.234 |
| 2009 - 2016 | 0.477 | 0.452 |

**Note:** Missing growth estimates are annual averages and in percentage points per year.

**Table 19:** Missing growth in Finland, France and the United States

| | Missing growth (FIN) | Missing growth (FRA) | Missing growth (USA) |
|---|---|---|---|
| 1996 - 2005 | 0.27 | 0.38 | 0.55 |
| 2006 - 2013 | 0.44 | 0.60 | 0.74 |

**Note:** Entries are percentage points per year and they are calculated with employment data. Results for France and USA are from Aghion, Bergeaud, Boppart and Bunel, 2018 and Aghion, Bergeaud, Boppart, Klenow and Li, 2017.

**Table 20:** Missing growth with different values of lag k

| | k = 1 | k = 3 | k = 5 | k = 7 |
|---|---|---|---|---|
| Revenue | 0.196 | 0.397 | 0.489 | 0.606 |
| Employment | 0.028 | 0.217 | 0.385 | 0.454 |

**Note:** Values are percentage points per year and averages for time period 1989-2016. $\sigma = 4$ has been kept unaltered.

**Table 21:** Missing growth with different values of $\sigma$

| | $\sigma = 2$ | $\sigma = 3$ | $\sigma = 4$ | $\sigma = 5$ | $\sigma = 6$ |
|---|---|---|---|---|---|
| Revenue | 1.467 | 0.734 | 0.489 | 0.367 | 0.293 |
| Employment | 1.156 | 0.578 | 0.385 | 0.289 | 0.231 |

**Note:** Entries are percentage points per year and averages for time period 1989-2016. The lag $k = 5$ has been kept unaltered.